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ABSTRACT

The acquisition of visual information, which occurs during eye fixations, involves two processes: registration (visual information becoming available to the brain) and utilization (visual information being used to further text comprehension). Registration occurs at the beginning of a fixation, while at least four possible patterns describe the points at which utilization occurs. It may occur: (1) immediately following registration; (2) from different regions at different times; (3) frequently throughout the fixation--continuous utilization; and (4) at a delimited point in time. In order to test these hypotheses, a series of experiments, all using a variation of the same methodology, was conducted. The results indicate that the fourth pattern--utilization occurring at a delimited point in time--best describes what occurs most typically during reading. Furthermore, the results present two possible versions of this hypothesis: that utilization takes place at the end of a fixation or after a fixation is terminated, and that the time of utilization varies--early or late in the fixation--influenced possibly by the needs of other on-going language processes. Further research is needed to examine these possibilities. (LLZ)

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CENTER FOR THE STUDY OF READING

Technical Report No. 356

INVESTIGATIONS OF INFORMATION UTILIZATION DURING FIXATIONS IN READING

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Abstract

A series of experiments, designed to investigate when information is utilized during fixations in reading is described with this report. Utilization refers to visual information being used to further the comprehension of the text being read, in contrast to registration, which refers to visual information simply becoming available to the brain. Four possible patterns of utilization are considered: (a) utilization immediately follows registration, (b) information is utilized from different text segments at different times, (c) utilization occurs continuously throughout the fixation, and (d) utilization occurs at a delimited point in time. In each experiment, subjects read short texts from a cathode-ray tube as their eye movements were monitored. During selected fixations, the text was briefly masked and then reappeared with one word changed. Subjects sometimes reported reading the first presented word, sometimes the second, and sometimes both. Several variations of this basic experimental paradigm were used to test four hypotheses about utilization. The results are most consistent with the possibility that utilization occurs at a specific point in time during a fixation.

Investigations of Information Utilization during Fixations in Reading

During the reading of connected text, visual information is acquired during fixations. When is visual information acquired during these fixations? In order to deal with this question, it is necessary to make clear what we mean by the "acquisition" of information. Acquisition can be distinguished into two processes, registration and utilization (McConkie, 1983). Registration refers to visual information becoming available to the brain. Utilization refers to the visual information being used to further the comprehension of the text being read. Registration is simply the transmission of retinal input to the brain. Each new fixation in reading makes a new pattern of stimulation available, and so registration occurs at the beginning of each fixation, given a delay of about 60 ms for transmission time from the eye to the visual cortex (Russo, 1978). Utilization, however, does not have to follow immediately after registration, although this is one possibility.

Hypotheses About Utilization

At least four different patterns of utilization are possible.

1. Utilization immediately follows registration. This expresses the common assumption (Gough, 1972; Just & Carpenter, 1980; Rayner, Inhoff, Morrison, Slowiaczek, &

Bertera, 1981; Smith, 1971) that the first 50 ms of each fixation is devoted to information acquisition and the remainder of the fixation period to other processing activities, such as comprehension and eye guidance.

2. Utilization from different regions at different times. Another possibility is that some sections of a word or text are utilized at different times than other sections. There are many possible patterns of this kind, but the most widely discussed is the left-to-right scan (e.g., Geyer, 1970; Gough, 1972; Heron, 1957; Mewhort, 1984, Mewhort & Campbell, 1981; McConkie, 1979; Sperling, 1963). This states that letters are utilized, one after another, in a left to right sequence, beginning at the left side of the field of clear vision and proceeding to the right.

3. Utilization occurs continuously throughout the fixation. It has been suggested that stimulus information is being noticed at all times during the fixation (Wolverton & Zola, 1983). This could be interpreted as continuous utilization.

4. Utilization occurs at a delimited point in time. Utilization could occur at a specific delimited point in time, as in the first alternative, but not necessarily linked to the process of registration. There are two possibilities here. First, utilization could occur at the end of a fixation or even after the fixation is terminated. Second, utilization could occur during the fixation, but

with the specific time of its occurrence being variable. Under this variable utilization time hypothesis, the time of utilization is determined by the current need of language processes (Blanchard, McConkie, Zola, & Wolverton, 1984). The purpose of this paper is to present evidence which narrows down these possibilities to the last alternative.

Blanchard et al. (1984) provided evidence on two hypotheses: utilization follows registration and the left-to-right scan. The further experiments reported here provide evidence on the left-to-right scan and continuous utilization hypotheses. These experiments all use a variation of the same methodology, which can be most easily explained by using the Blanchard et al. (1984) procedure as the prototype.

A Method for Studing the Time Course of Utilization

How can the time course of utilization be experimentally determined? The rationale of the Blanchard et al. (1984) procedure is to manipulate the visual input available during fixations in reading. If the presented visual information is changed during a fixation, then by observing what people report reading it is possible to infer what information was utilized. The most common way of changing visual information within the time frame of fixation is to use a tachistoscope. The same fast control over the stimulus provided by the tachistoscope can be obtained during the process of reading continuous text through the Eye Movement Contingent Display Change technique (McConkie,

Zola, Wolverton, & Burns, 1978). In this technique, the subject reads text from a cathode ray tube (CRT) linked to a computer and an eyetracker. The CRT provides the ability to change the text presented in any way desired very quickly (in the range of approximately 4 ms). While the subject is reading, his or her eye movements are being monitored. The signal from the eyetracker is collected by a computer, which identifies, on line, whether the subject is fixating or making a saccade. The text displayed on the CRT can be changed contingent upon what the subject's eyes are doing. For example, a brief masking pattern could be put up just during saccades (in which case the subject does not report seeing the mask) or, say, just 50 ms after the beginning of each fixation (in which case reading is disrupted to some extent). However, display manipulations can be even more sophisticated than this: the text ifself can be changed. For example, the text can be changed by switching a single letter on the line. This is the manipulation used by Blanchard et al. (1984).

Ninety-six passages were written in which two words fit into the same place in the text. For example,

> The underground caverns were meant to house hidden (tombs, bombs), but then the construction was stopped because of lack of funds.

Changing a letter, from t to b, changes the meaning of the text. This critical letter was changed partway through each fixation

that the subject made in the vicinity of the letter. The word in which the critical letter is embedded will be referred to as the critical word, will be described as changing during the fixation. At the beginning of a fixation, one word was in the text (tombs). Partway through the fixation, the line of text was replaced by a mask of X's for 30 ms, and the text was then returned to the screen for the remainder of the fixation. However, after the mask, the critical letter was different than it had been in the early part of the fixation, thus changing the critical word to bombs. During the saccade, bombs was changed back to the original word, tombs, and the cycle began again. In this way, the same sequence of display changes was repeated for each fixation-saccade cycle. This sequence of changes caused different information to be present in the early and late parts of the fixation. After reading text under these conditions, the subject was then asked about what word or words they read, tombs or bombs. From their answers, it can be inferred that utilization occurred early, late, or continuously throughout the fixation period.

The purpose of the mask in this experiment was to eliminate apparent movement which was localized at the critical letter position when the letter changed. The reader can notice display changes made any time during the fixation period (Wolverton & Zola, 1983). However, this does not necessarily bear on the question of when information is typically utilized

during the fixation. Localized apparent movement attracts attention away from its normal place to the location of the movement. The mask causes apparent movement at all letter positions equally, thus removing the effect caused by a localized change.

The subject was given four test words, one after another, after each passage. That is to say, the subject was asked which of four words actually occurred in the text. Two of the test words were the critical, changing words. Which word or words were reported indicated whether the critical letter was utilized before the mask, after it, or throughout the fixation. The experiment also included a control condition in which the mask occurred but the same critical word was present both before and after the mask. This provided a way of evaluating subjects' accuracy on this recognition test procedure.

One aspect which can be varied in this situation is the length of time the first word is present during each fixation. In Blanchard et al. (1984), the time the first word was present (also referred to as mask onset time) was varied between 50, 80, and 120 ms after fixation onset. The time the second word is present is uncontrolled, of course, because of the variable nature of fixation durations.

Basic Results

Given these experimental conditions, the hypothesis that utilization immediately follows registration predicts that only

the first word present during the fixation should be reported. (Some errors in the recognition test would be expected, of course, and some instances where subjects saw both critical words because they regressed and saw a different word, or because the mask inadequately masked the localized movement.) Blanchard et al.'s (1984) results do not conform to this prediction. Sometimes subjects reported reading the first word, sometimes both words, and sometimes they reported reading only the second presented word. Each of these reports occurred approximately a third of the time (29% for the first, 36% for the second, and 35% for both). Clearly, utilization does not inevitably occur at the beginning of the fixation--sometimes it occurs later in the fixation.

There was an important pattern to the reports which the remaining alternative hypotheses about utilization must be able to explain. Figure 1 shows this pattern: the longer the first word is present, the more likely it is that the first word will be reported and the less likely the second word is to be reported. This same relationship holds for the time the second word is present. When fixations on which the critical word is likely to be acquired are selected from the data, the same presentation time effect can be observed, that is, the longer the second word is present, the more likely the second word is to be reported and the less likely the first word is to be reported.

No clear pattern of this sort appears to hold for the likelihood of reporting both words.

Insert Figure 1 about here.

The Left-to-Right Scan Hypothesis

One possible explanation for this presentation time effect lies with the left-to-right scan hypothesis. In the long run, the longer a word is present during a fixation, the more likely it is that the scan will reach the critical letter while that word is present. Blanchard et al. (1984) conducted two tests for the scan hypothesis. First, the position of the critical letter in the critical word was varied so that in half of the texts it was the first letter (e.g., tombs-bombs) and in the other half it was the fourth letter (e.g., snake-snare). If a left-to-right scan were taking place, then the initial letter should be utilized earlier than other letters, e.g., the fourth. Therefore, the first word should be reported more often when the first letter changes and less often when the fourth letter changes, and the opposite should be true for reporting the second word. The actual results did not show this pattern. The likelihood of reporting the two words was the same, regardless of whether the first or fourth letter was changing. The second test concerned a necessary consequence of the scan hypothesis, that the critical letter will be encountered by the scan either early

or late in the fixation, depending on where the scan begins with respect to the location of the critical letter. Where the scan begins should depend on where the fixation is located with respect to the critical letter. Specifically, the word present early in the fixation should be more frequently reported when the fixation is to the right of the critical letter and less frequently reported when the critical letter is to the left of the critical letter. The opposite should be true of the word present later in the fixation (see Figure 2). Again, the actual results show that the probability of reporting the first word only or the second word only does not vary as a function of the location of the fixation with respect to the critical letter (see Figure 3).

Insert Figure 2 & 3 about here.

These results from Blanchard et al. (1984) are not consistent with the left-to-right scan hypothesis (with the exception of hypotheses of very fast scans or scans of word rather than letter units). However, because the scan hypothesis has occupied so much attention in the visual perception literature, and because it could provide a very parsimonious mechanism for eye guidance (see McConkie, 1979), two additional experiments were specifically designed to test this hypothesis.

Experiment

In Experiment 1, the same technique as Blanchard et al. was used, except now there were two critical letters in a critical word instead of just one. Texts from McConkie, Zola, Blanchard, & Wolverton (1982) were used in which four words contrasting by two letters all fit into the same position in the text, for example,

> Ruth's great aunt is definitely the most (mushy, musty, gushy, gusty) person she has ever met.

During fixations in reading, the two critical letters were changed (with an interpolated mask occurring 80 ms after fixation onset), so that one of the four possible words was present during the early part of each fixation (mushy) and a second word during the latter part of each fixation (gusty). The other two words were never presented. If a left-to-right scan were taking place, it would be expected that at least sometimes the first critical letter from the first word and the second critical letter from the second word would be utilized, causing the subject to report reading a word that was never present on the screen (musty in this example, see Figure 4). The frequency of this phenomenon would depend on the speed of the scan and on where the scan begins (and, therefore, on where the fixation was with respect to the critical letter).

Insert Figure 4 about here.

The results were much like Blanchard et al. (1984) in that the subjects sometimes reported the first present word, sometimes the second word, and sometimes both words. However, they did not report the musty-type non-presented words which would be expected from a left-to-right scan hypothesis with a frequency greater than that expected purely by subject error. Also, there was no pattern of the frequency of such reports varying with where the fixations were with respect to the position of the critical letters. Thus, no support was found for a left-to-right scan.

Experiment 2

In Experiment 2, the same basic procedure as in Experiment 1 was used, except that now every letter in the critical word was changed after the mask was removed during fixations. Ninety-six passages were written in which a pair of critical words differing at every letter position fit into the same position in the text, for example:

> Sandy spent a long time preparing the (melon, cakes) for dessert and completely forgot about the hors d'oeuvres.

In this case, if a left-to-right scan takes place, there should be some instances where some letters from first presented word and some letters from the second presented word are utilized

together. In this case, the subject could perceive a non-word as a result, although the perceptual system may also allow some kind of error recovery, where perhaps both critical words are consciously perceived. Instances where only one critical word is reported would be expected in cases where the scan traversed all the letters of the critical word competely before or after the mask replaced the text. These instances would have to be cases where the scan started very close to or far away from the critical word, thus, again, predicting differences in which word or words are reported as a function of the location of the fixation.

The results of changing an entire word during a fixation resemble the original results of Blanchard et al.'s (1984) single letter switch, in that sometimes a single word was reported and sometimes both critical words were reported. However, the relative frequency of reporting both critical words present during the fixation doubled with respect to the single letter change experiment. This may be due either to the greater possibility of localized movement being perceived despite the mask or to the greater disruption to the perceptual processes prior to utilization. With respect to the scan hypothesis, subjects did not report seeing non-words, and there was no change in the pattern of single versus both word reports as a function of fixation location (see Figure 5).

Insert Figure 5 about here.

The results of these three experiments clearly rule out the left-to-right scan as a possible pattern of utilization. Other possible sequences of utilization of text segments are also unlikely, such as acquiring the end letters of a word before the central letters or a scan of syllable units. Scans occurring at very fast rates (greater than 10 ms per letter) or scans in which words are units are not ruled out by these data.

The Memory Process Explanation

The next possible pattern is continuous utilization throughout the fixation. This would seem to be ruled out by Blanchard et al.'s (1984) basic results. For 65% of the time, subjects reported reading only one critical word from which it is inferred that utilization did not occur for the entire duration of the fixation. If such were the case, subjects should report both words all the time. (The instances where subjects do report both words could be due either to continuous utilization or to subjects noticing the change.) However, there is a way in which this pattern of utilization can be made compatible with the observed results. The reports of reading a single word could be explained through the action of memory processes rather than through perceptual processes. It is possible that subjects' reports of reading single critical words are due to processes at a

stage much later than the time of utilization. Under this alternative hypothesis, both critical words present during a fixation are always perceived (utilized), but one of the critical words is more susceptible to forgetting than the other. Essentially, the perceptual processes during each fixation are assumed to be more or less identical, regardless of what the subject later reports during the recognition test. Cases where the subject reports reading only a single word are caused by forgetting processes operating after utilization.

This explanation by memory processes is consistent with the findings presented so far. The effect of presentation time on whether the first or second critical word is reported can be explained by this hypothesis if the following assumption is added: the longer a word is present during a fixation, the better "consolidated" it becomes in memory, or perhaps when the word is present longer it has an opportunity to be processed to a "deeper level" of processing, and so becomes less susceptible to forgetting. Depending on how long a word is present, and other factors such as context, the memory representation of a critical word may or may not be strong enough to elicit a "yes" response on the recognition test. Thus, reports of one or both critical words will be observed, depending on memory variables, but not on processes operating during a fixation.

There is data from Blanchard et al. (1984) which is difficult to explain under this memory process hypothesis. The

durations of fixations on the critical word for cases in which subjects later reported reading a single word were compared to cases where both words were later reported and to the control condition where no change occurred. The mean fixation duration of the single word report cases was not statistically different from the mean for the control condition, whereas the both word cases showed a large, significant increase in fixation duration. This strongly suggest that there is an immediate perceptual disturbance in the both word cases that did not occur in the single word report cases. Thus, there seems to be a difference at the time of perception, which is not compatible with a purely memory-based explanation.

Experiment 3

Two experiments were conducted to further test the memory process hypothesis. In Experiment 3, the display changes and texts were similar to those used by Blanchard et al. (1984), in that a single letter was changed during fixations. However, subjects in the current experiment were instructed to press a button while they were reading if they observed a word change. These were all non-naive subjects, so they were quite aware of what a letter change looked like. A pure memory process explanation requires that there should be no correlation between the indications of seeing a letter change and the recognition test results. An explanation by perceptual processes predicts that when subjects report on the recognition test that they read

one critical word, they will not have indicated seeing a change while reading the text. The results are consistent with the latter explanation (see Figure 6). When subjects did indicate seeing a letter change, they reported both words on the recognition test 92% of the time. Performance on the recognition test appears to accurately reflect what subjects are detecting during their on-going reading.

Insert Figure 6 about here.

Experiment 4

In Experiment 4, the single letter change technique was again used to test the memory process explanation. On half of the passages in this experiment, the text was removed from the screen completely during a saccade taking the eyes away from the critical word. When this happened, subjects were instructed to verbally report the last few words that they remembered reading, and to report any letter changes they had detected. This turn-off-the-test technique (see McConkie & Hogaboam, in press), combined with the letter change during fixations, allows an alternative method to the recognition test used in the earlier studies. However, this technique greatly reduces non-immediate effects such as memory processes, by obtaining reports very soon after the critical word was fixated. In addition to the experimental condition, where the letter change was made, a control condition

was included in which there was no change in the critical word. The text was turned off on half of the texts assigned to the experimental condition and on half assigned to the control. On the remainder of the texts, subjects proceeded through the whole text without interruption and then performed the recognition test, just as subjects did in the previous studies. This allows comparison of the two testing methods and assessment of the influence of non-immediate effects on subjects' reports.

Figure 7 compares the recognitionest results with the results from the immediate verbal reports. There is essentially no difference between these conditions in the pattern of reporting on critical word versus both critical words. This is in direct contradiction to the memory process explanation, which predicts that subjects should always be able to report both critical words present, because they do not have an opportunity to forget one of the words. At the very least, the probability of reporting both critical words should increase with the immediate verbal reports, but this is not the case. In addition, the presentation time effect is not different in the recognition test and turn-off-the-text conditions. It seems safe to conclude that the pattern of reporting observed in the recognition tests of this and previous studies largely reflects processes that are occuring during perception, or, at least, during the very early stages of processing. These results do not support the memory process explanation, and so are not consistent with the

hypothesis that utilization occurs continuously throughout the fixation. The results are consistent with the possibility that utilization occurs during a specific, delimited point in time during the fixation.

Insert Figure 7 about here.

Conclusion

These experiments have clearly narrowed down the possible patterns of utilization as described above. Utilization does not typically occur immediately after registration, although it may sometimes. There may be atypical situations which force utilization to occur immediately after registration. One such case might be a situation used by Rayner et al. (1981), in which all but the first 50 ms of each fixation is masked. What the present series of studies indicate is that this is not a typical pattern in reading. Also, letters are not utilized in a left-to-right scan. Other possible patterns of utilization of different text segments at different times are not likely.

Finally, utilization does not appear to occur continuously throughout the fixation. This may appear to contradict the results of Wolverton and Zola (1983) which indicated that changes in the text are noticed at any time during the fixation. Unusual events, such as a mask or the localized apparent movement caused by an unmasked changing letter, cause an

atypical diversion of processing. Again, this does not indicate the typical state of processing in continuous reading. The technique used in these studies attempted to ivestigate typical processing by minimizing attention diverting effects. Under these conditions, subjects frequently do not report reading all of the information available during a fixation, viz. they do not always report both critical changing words.

This leads to the last possibility, that utilization occurs at a delimited point in time during the fixation. There are two possible versions of this hypothesis. In one, the pattern of sometimes reporting a single word, along with the presentation time effect, is attributed entirely to the pattern masking characteristics of the interpolated mask. The mask is viewed as a backward mask for the first presented word and a forward mask for the second presented word. As presentation time increases, the effectiveness of the mask decreases, thus increasing the probability of reporting the critical word. One or both critical words will be reported, depending on the effectiveness of the mask for each critical word during an individual fixation. This involves a kind of indirect competition between the two words present during a fixation. Visual information is available from both words when utilization takes place, although either one or both words may be perceived. One implication of this possibility is that utilization must take

place at the end of the fixation or after it is terminated, in order for information from both words to be available.

The other possibility is that reports of reading a single critical word directly indicate when utilization occurs during a fixation. This is, the fact that the subject reports the word present early in the fixation or the word present later in the fixation corresponds to the actual point during the fixation at which utilization occurred. If this is so, then the time of utilization would appear to vary, occurring sometimes early and sometimes later in the fixation. This was proposed by Blanchard et al. (1984). It can be further speculated that the variable time utilization is influenced by the current need of concurrent language processes. When on-going language comprehension is ready to accept new input, then utilization will occur. This activity will not be in direct correspondence with the saccade-fixation cycle, so the time of utilization will vary independently of the making of a new fixation. Further research is necessary to examine these two possibilities. Such research is being done in our laboratory using the letter change during fixations technique.

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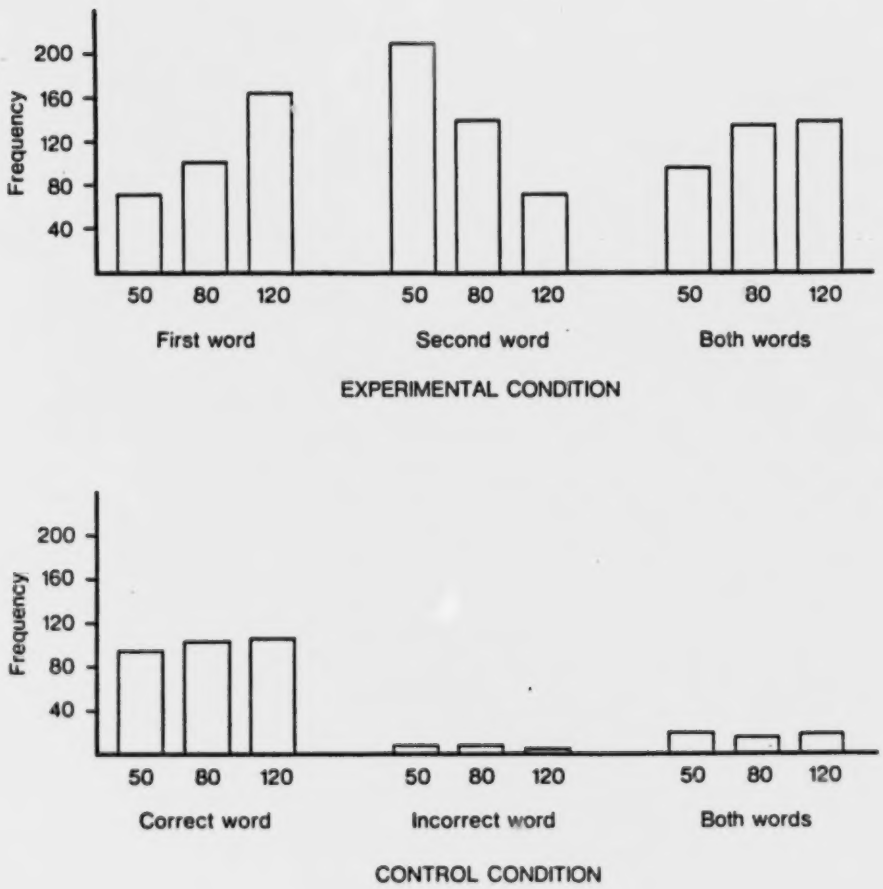

Figure 1. The frequency of subjects' reports of reading one or both of the critical words in Blanchard et. al. (1984). Frequencies are shown for the 50, 80, and 120 ms mask onset times of the experimental and control conditions.

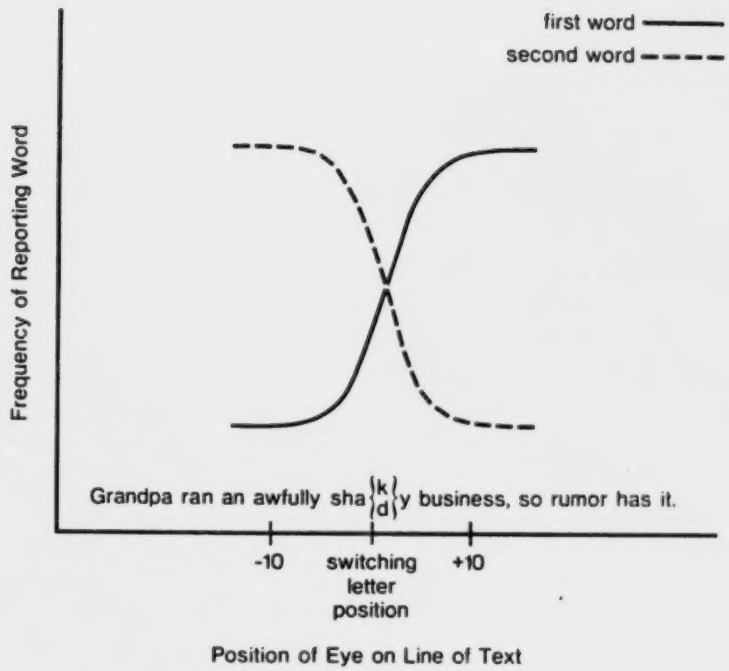

Figure 2. Pattern of results expected by a left-to-right scan hypothesis in the experiment done by Blanchard et al. (1984). The negative position indicates a letter position to the left of the position of the critical letter.

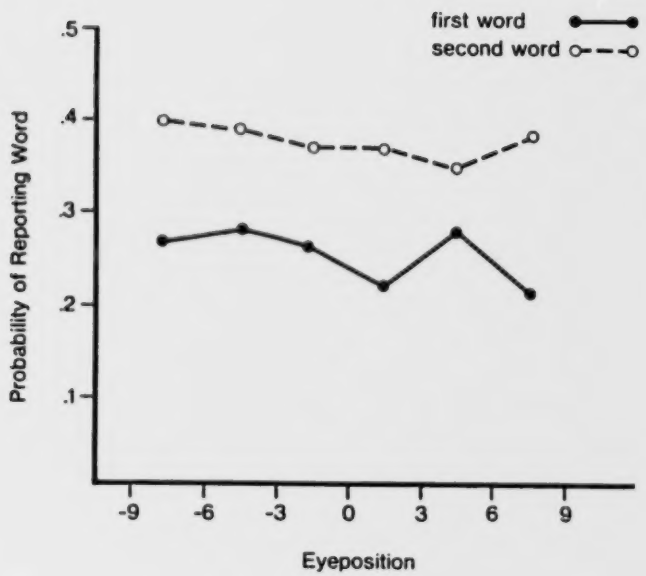

Figure 3. Actual results found by Blanchard et al. (1984) for the situation presented in Figure 2. Eyeposition values indicate the number of character positions away from the critical letter position, where negative values are to the left of the critical letter.

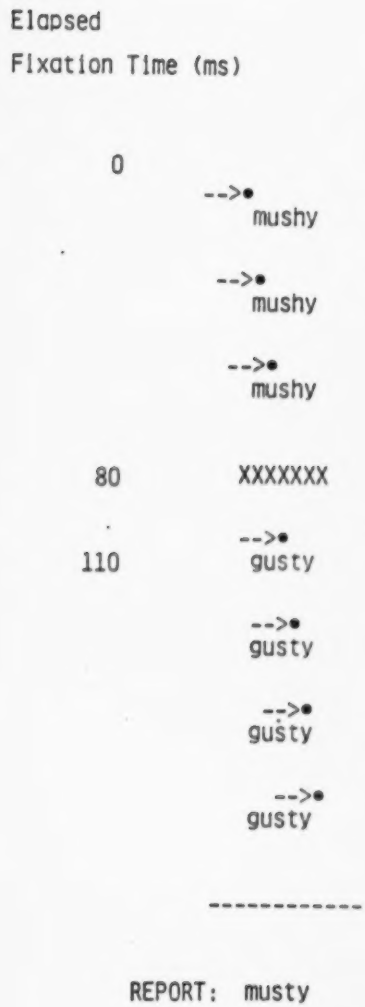

Figure 4. Schematic representation of one hypothetical situation in Experiment 1 which would be expected from a left-to-right scan hypothesis.

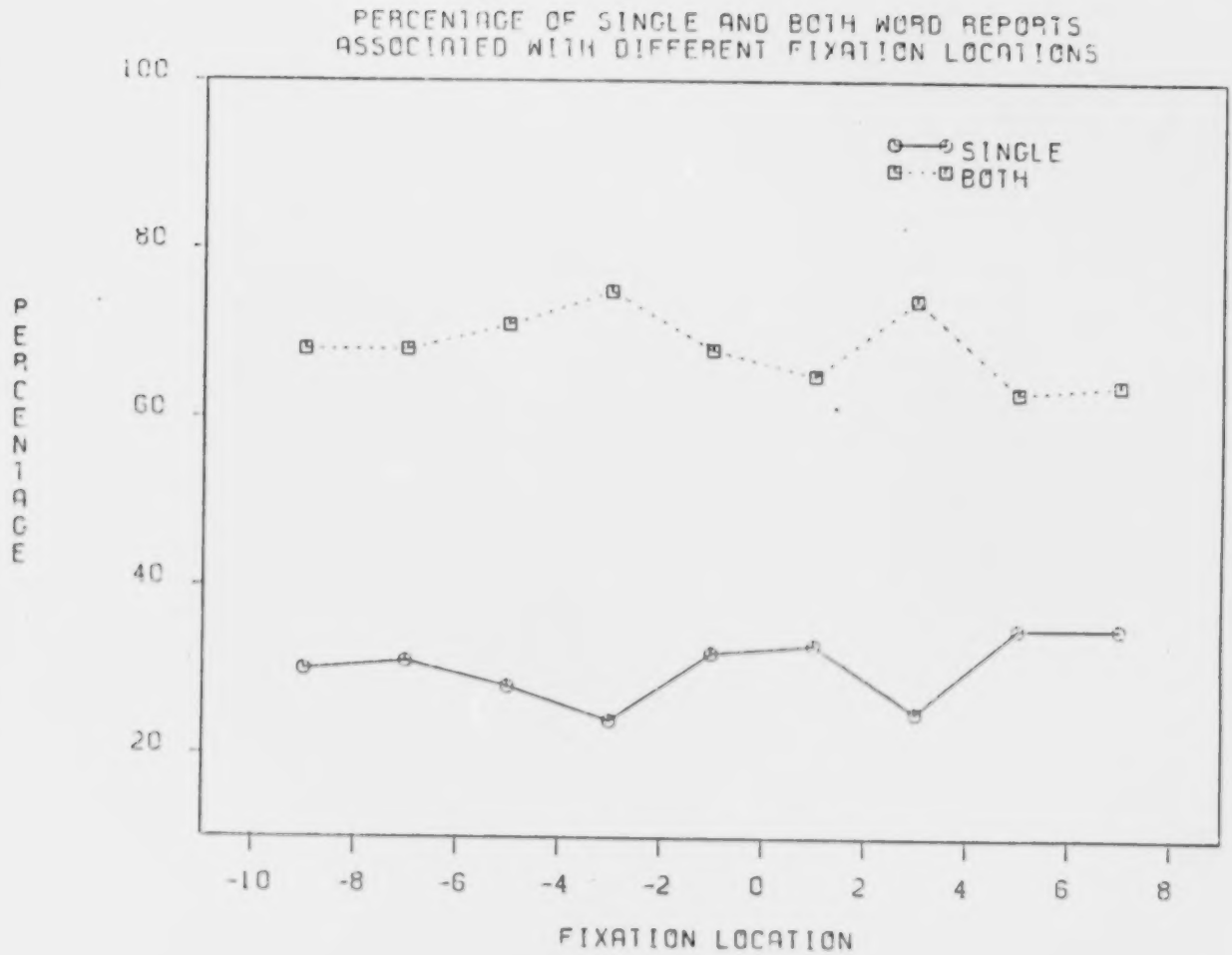

Figure 5. Percentage of single and both word reports given after fixations centered at different positions in Experiment 2. Fixation location values indicate the number of character positions away from the first letter of the critical word, where negative values are to the left of the first letter.

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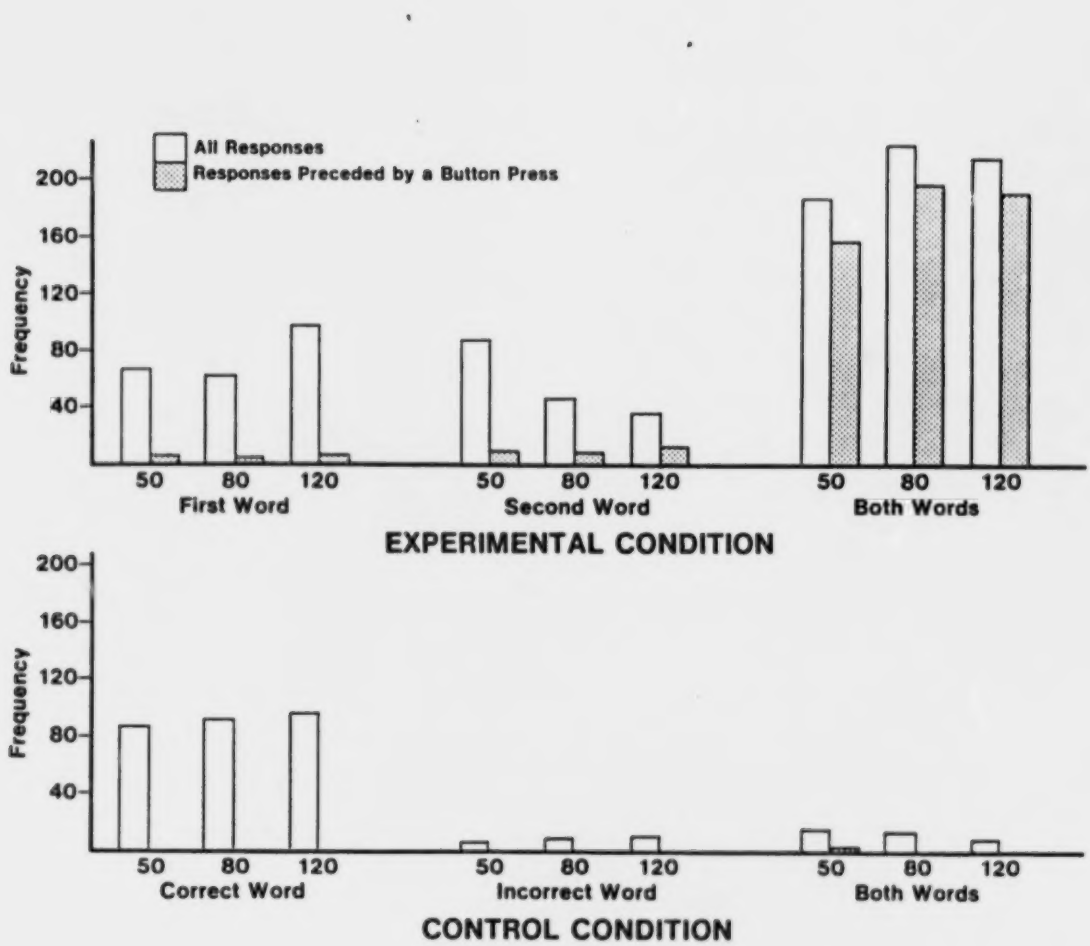

Figure 6. The frequency of subjects' reports of reading one or both of the critical words in Experiment 3, along with the number of sentences on which the subject indicated seeing a change during reading.

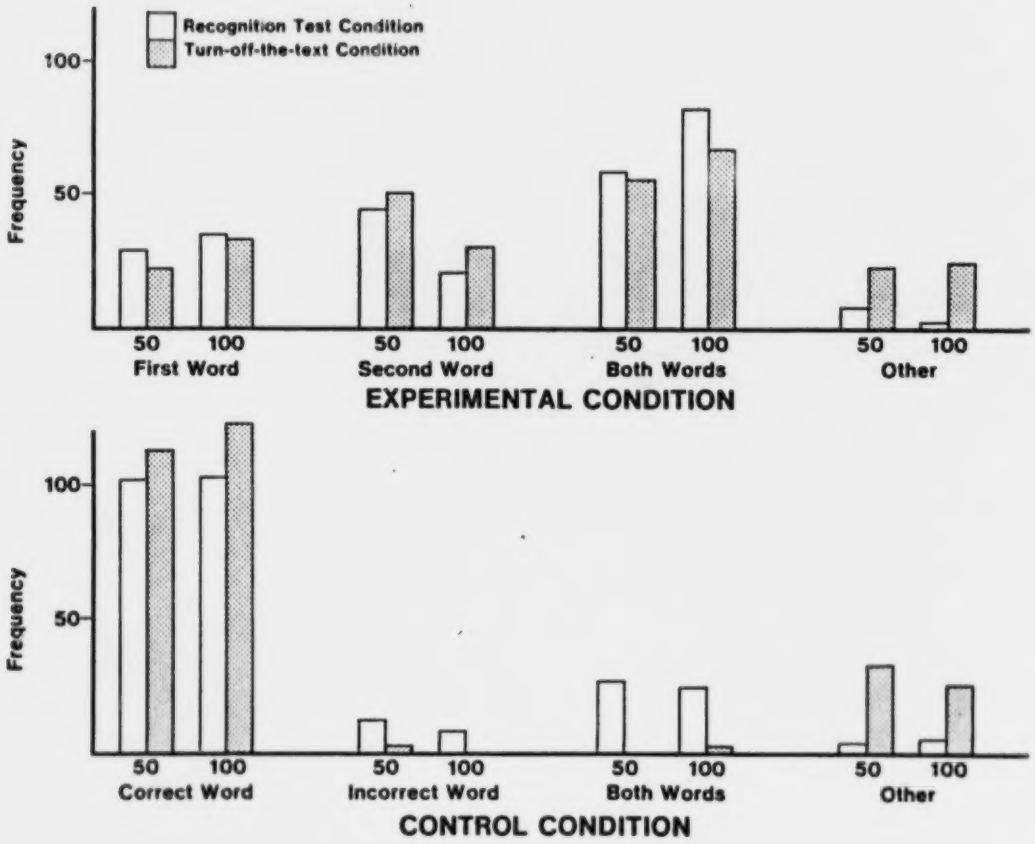

Figure 7. The frequency of subjects' reports of reading one or both of the critical words for the two conditions of Experiment 4.